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Colloquia: Transversity 2011

GPDs and Drell-Yan processes at COMPASS and NICA

O. V. Teryaev and A. P. Nagaytsev
Joint Institute for Nuclear Research - 141980 Dubna, Russia

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Summary. — The NICA experiment at JINR is described in some detail. We also discuss the Drell-Yan process and what one can extract from the experimental data at planned COMPASS and NICA experiments about the Generalized Parton Distributions and pion Distribution Amplitude.

PACS 11.15.Bt – General properties of perturbation theory.
PACS 12.38.Bx – Perturbative calculations.
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1. – Introduction

The Drell-Yan (DY) process is known to be one of the major hard processes providing information about various non-perturbative ingredients of nucleon. This paper contains the discussions of some complementary features of both its theoretical and experimental aspects.

From the experimental side, the respective programs at various facilities (especially, of course, at COMPASS) are much discussed at this conference and we will describe here (A.P. N., sect. **2**) the complementary program at NICA facility at JINR.

From the theory point of view, we will consider here the studies of exclusive limits (O.V. T., sect. **3**) which provide an access to Generalized Parton Distributions and pion Distribution Amplitude.

2. – NICA at JINR

The goal of the NICA project is the construction at JINR of a new accelerator facility that consists of cryogenic heavy ion source, source of polarized protons and deuterons, "old" linac LU-20, a new heavy ion linear accelerator, a new Booster-synchrotron, the existing proton synchrotron Nuclotron, upgraded to Nuclotron-M, two new superconducting storage rings of the collider, and a new set of transfer channels (fig. 1).

The facility will have to provide: ion-ion (Au) and ion-proton collisions in the energy range 1–4.5 GeV/u and luminosity up to $L \sim 10^{27}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and collisions of polarized

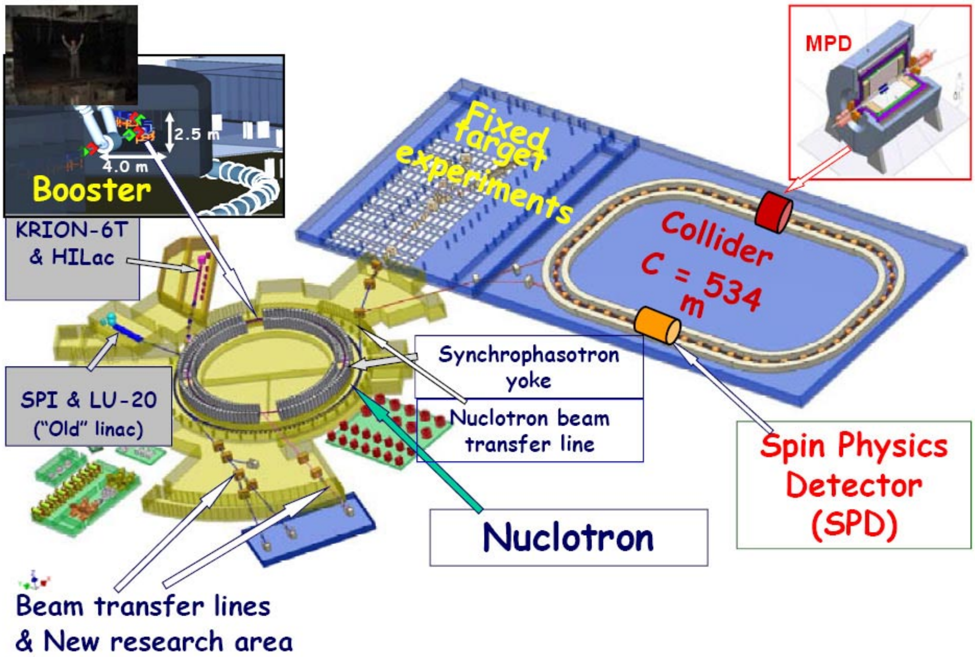

Fig. 1. – Scheme of the Nuclotron-based Ion Collider fAcility (NICA).

proton-proton (deuteron-deuteron) beams in the energy range 5–12.6 GeV (2–5.8 GeV/u) with luminosity $L > 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. Using Nuclotron-M and NICA facilities the following set of experiments can be planned: fixed target experiments, experiments with internal target, collider experiments with two interaction points and, respectively, with two detectors. The first is the Multi Purpose Detector (MPD), aimed for experimental studies of hot and dense strongly interacting QCD matter and search for possible manifestations of the mixed phase and of critical endpoint in heavy ion collisions. The second detector will be used for the spin studies and named as Spin Physics Detector (SPD).

2˙1. *Spin Physics at NICA*

2˙1.1. Polarized Beam Source. The polarized ions project foresees the design and construction of a universal high-intensity source of polarized deuterons (D) and protons (H) using a charge-exchange plasma ionizer. The output D^+ (H^+) current of the source is expected to be at a level of 10 mA. The polarization will be up to 90% of the maximal vector (+1) for $D^+(H^+)$. Tensor polarisation for the deuteron will also be available. The new source will make it possible to have the polarized deuteron (proton) beam intensity up to the level of 10^{10} d(p)/pulse. The realization of the project is carried out in close cooperation with INR of RAS (Moscow), and the equipment is based on the CIPIOS ion source (IUCF, Bloomington, USA).

2˙1.2. Polarimetry. The measurements of the beam polarization at Nuclotron-M and NICA collider are very important and aim to provide both the absolute measurements with a relative accuracy better than 3–5% and a continuous monitoring of the polarization. These measurements are based on the monitoring of the known analyzing power

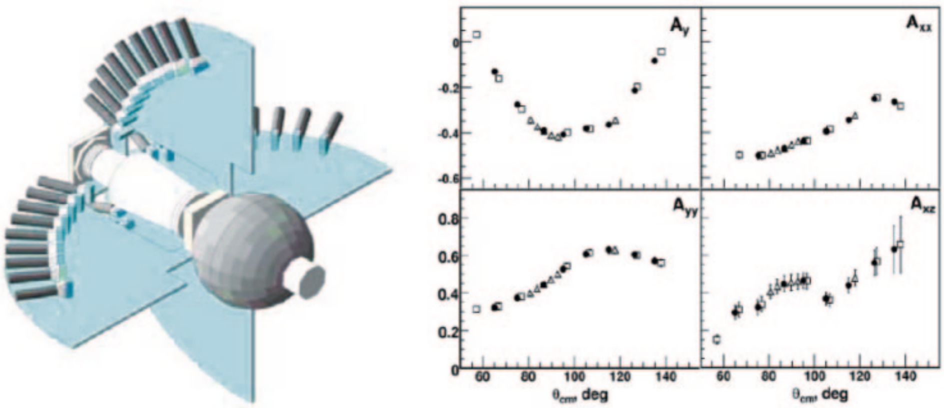

Fig. 2. – The view of the CNS detecting system (left) and results for the analyzing powers in dp-elastic scattering (right).

in various elastic, quasielastic and inelastic processes (fig. 2). Several measurements are under preparation within the Beam Polarization Project measurements: 1. Absolute calibration of the beam polarization; 2. Efficient calibrated polarimeters; 3. Permanent monitoring of the beam polarization; 4. Local polarimetry. To perform these tasks the measurements of the analyzing power in various elastic and quasielastic processes (dp, pp, pC, dC) will be performed.

2˙1.3. Proposed measurements. The parameters of the NICA collider allows to study: 1. DY processes; 2. J/Ψ production processes; 3. Elastic reactions; 4. Spin effects in one and two hadron production processes; 5. Spin effects in inclusive high-p_T reactions; 6. Polarization effects in heavy ion collisions; 7. Spectroscopy of quarkonia with any available decay modes.

The studies of DY processes in collisions of transversely polarized protons and deuterons provide an access to the very important and still poorly known sea and valence transversity, Boer-Mulders and Sivers PDFs in the proton. To determine Boer-Mulders and Sivers PDFs the following measurements must be performed: unpolarized and singly polarized DY processes with pp and pd collisions; J/Ψ production processes with unpolarized and singly polarized pp and pd collisions, which cannot be performed duplicated by other experiments (COMPASS, RHIC, PAX and JPARC). The measurements of J/Ψ production processes are very important for tests of duality model (see fig. 3).

The data on J/Ψ production on unpolarized targets which can be obtained with SPD at NICA, will essentially improve our understanding of the production mechanism. The measurements can be performed at various energies of NICA beams. The kinematical ranges are shown in fig. 4.

To estimate the possible precision of the measurements of the asymmetries a set of original software packages (MC simulation, generator, etc.) was developed. The single spin asymmetries (SSA) which can be measured with SPD NICA detector (see sect. **2**˙2) are shown in fig. 5. The two left panels present the dependence on x_F of the SSA giving access to transversity and Boer-Mulders PDFs, and the two right panels provide the same information for the Sivers PDFs. All SSA are estimated for 10^5 DY events, which could be collected in two-three years of data taking.

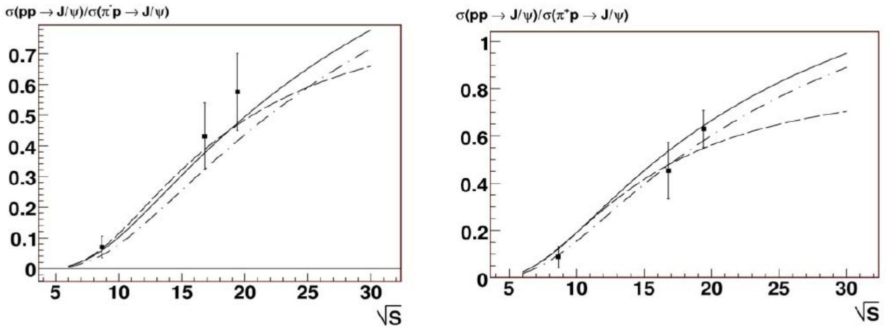

Fig. 3. – Ratios of cross-sections for prediction of J/Ψ in pp and πp interactions calculated with three models in comparison with the experimental data. The solid line corresponds to the "duality" model, the dashed line corresponds to the "gluon evaporation" model, and the dot-dashed line corresponds to "gluon evaporation" model without gluon contribution. The data points are from ref. [1].

Concerning the studies of polarization effects in heavy ion collisions with the MPD detector, the following polarization observables may be studied:

– Polarization of Λ as a probe of formation of isotropic matter.

– Correlations of Λ polarization with charge separation as a complementary signal for CP-violation in dense matter.

– Transverse handness as a probe for collective orbital momentum of the matter.

– Tensor polarization of dileptons as a complementary probe of matter formation, dilepton production mechanisms and collective orbital momentum.

2˙2. *SPD detector*. – The preliminary design of SPD detector for spin effects studies is based on the requirements imposed by the DY and J/Ψ productions studies. These requirements are the following: almost 4π acceptance for secondary particles; precise

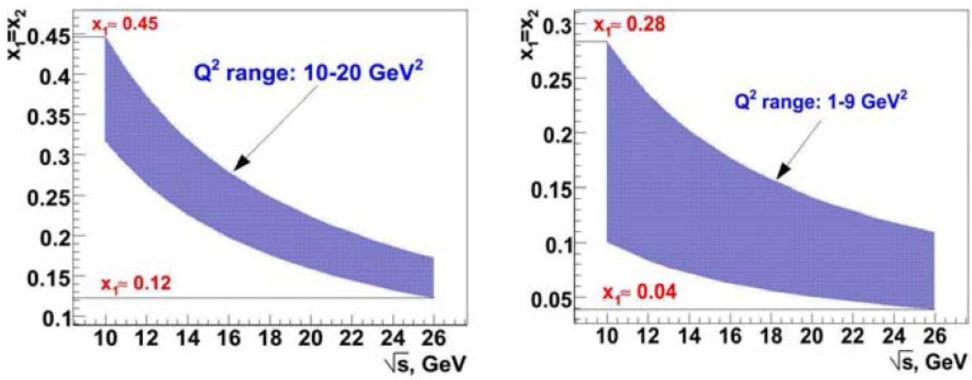

Fig. 4. – Available range for the x Bjorken variable *versus* $\sqrt{s}$ for J/Ψ production measurements at NICA.

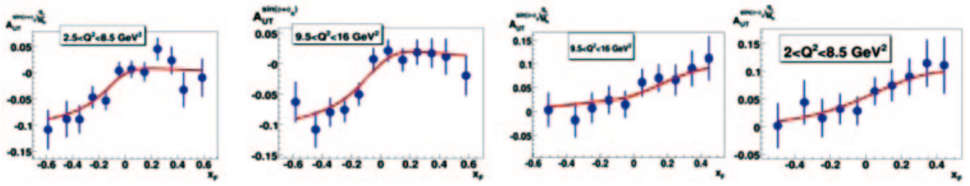

Fig. 5. – The SSA asymmetries which can be measured with the SPD NICA detector. The points give the expected precision. The two left panels demonstrate the access to transversity and Boer-Mulders PDFs, and the two right panels show the predictions to access the Sivers PDFs.

vertex detector; precise tracking system; precise momentum measurement of secondary particles; good particle identification capabilities. Most of these requirements are also good for the other studies mentioned above. The preliminary design of SPD is shown in fig. 6. The main parts of this scheme are described below. The toroid magnet of the spectrometer provides a field free region around the interaction point and does not disturb the trajectories. The toroid magnet consists of 8 superconducting coils symmetrically placed around the beam axis.

2·3. *Summary.* – The proposal for spin studies at NICA is under preparation. The purpose of the proposed measurements is the study of the nucleon spin structure with high intensity polarized light nuclear beams. One can perform these studies taking advantage of the main parameters of the NICA polarized beams: high collision proton (deuteron) energy up to $\sqrt{s}$ 26(12) GeV; the average luminosity up to $10^{30-31}\,\mathrm{cm}^2/\mathrm{s}$; both proton and deuteron beams can be effectively polarized. The NICA Spin program milestones are: during 2010-2014 it is planned to prepare the Conceptual Design Report and then the Technical Design Report, to organize the SPD collaboration and to perform main part of the R&D for SPD detector; in 2015-2018 we plan to finish the preparation of NICA polarized beams, finalize R&D studies for SPD detector and SPD detector production; in 2018 it is planned to start the SPD assembly, installation and tests and in 2019 the

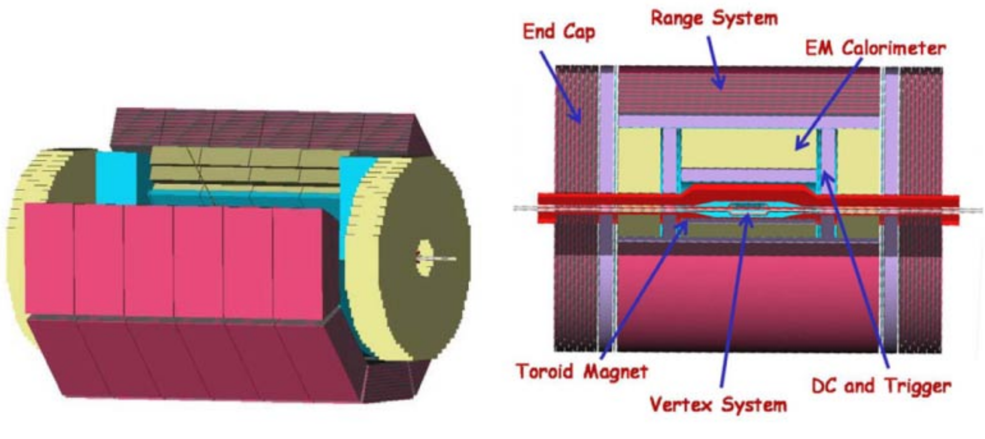

Fig. 6. – The views of SPD.

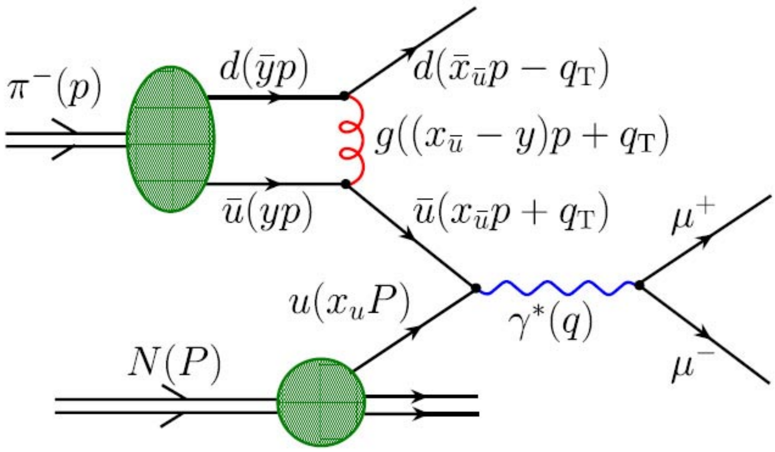

Fig. 7. – Semi-exclusive Drell-Yan process.

commissioning, and the start of data taking. NICA Spin studies with the MPD detector (start of operation in 2015-2016) is also under consideration.

3. – Exclusive limits of Drell-Yan processes

3˙1. *Semi-exclusive Drell-Yan process.* – The first of the exclusive limits suggested [2] by Stan Brodsky (who extensively discussed it in this conference) and collaborators corresponds to the situation when the dilepton pair created in collisions of pions (with momentum $p_1 = p$) and nucleons (with momentum $p_2 = P$) is produced in the fragmentation region of the pion beam, and the non-perturbative ingredient of QCD factorization corresponding to the pion is its distribution amplitude (DA) rather than parton distribution (see fig. 7).

Such a situation occurs in the limit of the pion momentum fraction going to 1. The kinematical regions can be conveniently described by the Sudakov decomposition of the virtual photon momentum

$$Q = x_1 P_1 + x_2 P_2 + Q_T, \tag{1}$$

and the semiexclusive region correspond to $x_1 \sim 1$.

The dilepton angular asymmetries for both spin-averaged [2,3] and (especially) polarized [4,3] proton target are very sensitive to the pion distribution amplitude and provide its important complementary probe which is of special interest due to so-called BaBar puzzle.

3˙2. *Exclusive Drell-Yan processes.* – If one additionally assumes that the transverse momentum Q_T is small, the unobserved d-quark (on the top of fig. 7) carrying the momentum $x_u p_2 + p_1 - q = (x_u - x_2)p_2 + (1 - x_1)p_1 - q_T$ becomes collinear to the proton and may be absorbed by its remnant forming the Generalized Parton Distribution (squared). Whether one has here another manifestation of duality [5] between different mechanisms of QCD factorization remains to be studied.

As the kinematical region of exclusive DY process is determined by the kinematics of the lepton pair ($x_1 \sim 1, Q_T \sim 0$) it can be studied even if the final proton is not detected.

In the case of proton-proton, deuteron-proton, or deuteron-deuteron collisions at NICA exclusive DY should be described by Transition Distribution Amplitudes p $\rightarrow$ 2p, p $\rightarrow$ He^3, D $\rightarrow$ He^3, D $\rightarrow$ He^4. These objects are now extensively studied [6] for transitions $\pi \rightarrow B$. The hard parts correspond to the exchange of three or six quarks and the latter should be strongly suppressed. It seems also promising to consider the ratio of exclusive DY amplitude and nucleon form factors which possess the same hard parts.

There is another possibility for exclusive DY process when both colliding hadrons are described by GPDs [7,8]. The factorization is violated if this amplitude is calculated directly which, after the possibility of the factorization violation inspired by BaBar puzzle (see, *e.g.*, [9] and references therein), does not seem so dramatic.

Note that this mechanism may occur at any longitudinal momentum fraction of the dilepton with small $Q_T \sim 0$, and therefore the identification of the final particles is required, which is currently not planned either at COMPASS or at NICA but may be possible in the central exclusive production at LHC.

3˙3. *Summary.* – The exclusive limits of DY process offer the exciting new theoretical possibilities to study the important ingredients of hadron structure like DAs and GPDs. Their feasibility in the experiments presently planned remains to be studied.

4. – Conclusions

There is an important ongoing complementary (to COMPASS and other experiments worldwide) program of spin physics studies, including that of DY process, at NICA.

It may also provide (together with COMPASS and other experiments) the attracting opportunities of investigations of exclusive limits of DY processes.

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